LEVEL II

12

AD A109375

DTIC FILE COPY

SRI International

February 1981

VENTILATION CONTROLLED FIRES

Smoke Obscuration and Venting in Cable Fire Tests

By: Raymond S. Alger
Frank I. Laughridge
Walter H. Johnson
Daniel D. Lee

Prepared for:

NAVAL RESEARCH LABORATORY
Washington, D.C. 20390

Attn: Code 6180, Dr. J. Leonard

Contract No. N00173-80-C-0144
SRI Project 1641
Final Report on FY-80 Task

SRI International
333 Ravenswood Ave. • Menlo Park, CA 94025
(415) 859-6200 • TWX: 910-373-2046 • Telex: 334 486

Accession For	
NTIS GRA&I	X
DTIC TAB	☐
Unannounced	☐
Justification	
By Per Ltr. on file	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A	

1. Introduction

Since John Paul Jones stood on the blazing Bon Homme Richard and challenged the British with those unforgettable words, "I have not yet begun to fight," the U.S. Navy has accumulated over 211 years of experience coping with ship fires. Despite this history and a strong tradition of fire fighting, some of the simple questions about fire characteristics and the suppression of compartment fires still defy the experts. This report is concerned with three of these areas of uncertainty.

- How do fires in forced ventilation compartments behave when extemporaneous holes are introduced in the bulkheads and/or decks by enemy action or the efforts of fire fighters trying to ventilate the space or apply an agent to the fire?
- When should ship compartment fires be sealed and when should they be ventilated to remove smoke and heat so the firemen can reach the seat of the fire?
- How do smoke and the hot combustion products behave during fire suppression efforts with water, particularly how do drop size and spray pattern disturb the fire environment and alter the thermal insult experienced by the fire fighters?

The first question involves an extension of knowledge on the effect of ventilation parameters (airflow amount and pattern) on shipboard compartment fires as developed under this program (Reference 1) to more complicated ventilation conditions. Questions 2 and 3 involve the application of knowledge, techniques, and facilities developed in the study of forced ventilation controlled fires (Reference 2) to a specific fire problem; namely, the location of cable fires and their suppression with water sprayed from hand lines. Shipboard cable fires continue to present a difficult problem in fire extinguishment owing to the inability to locate and deal with such fires effectively with present procedures. Recent engine room fires have had major cable involvement and indicate an opportunity to critically review the damage control procedures for extinguishing such fires. This report covers the first year of a multiyear program on Questions 1 and 2; therefore, only the beginning of the answers

has emerged, e.g., the scope of this report is limited to one particular class of cable fires that provided a very modest fire suppression challenge.

2. Apparatus and Procedure

The experimental parameters of interest fall into the following categories:

- Controlled variables
  - Forced ventilation rate and pattern
  - Free ventilation pattern
  - Fuel, type, amount, location and distribution
  - Water spray amount, rate, drop size and pattern.
- Measured variables
  - Burning rate . . . . weighing platform
  - Heat flux (thermal insult) . . . . radiometers
  - Gas temperatures . . . . thermocouples
  - Smoke densities . . . . photocells
  - Gas composition . . . . IR analysis, etc.
  - Temperature in cable pile . . . . thermocouples
  - Water runoff . . . . calibrated barrel

2.1 Test cell and experimental arrangement

Figure 1 shows the location of the simulated ship's compartment with respect to the other test chambers at Camp Parks. The 10 x 12 x 12 foot steel fire box rests on a concrete drainage basin that collects the runoff water from extinguishment exercises and deposits it in a calibrated sump. Smoke under forced ventilation conditions feeds into the scrubber attached to the concrete blockhouse and signals from the various monitoring systems go to the control building. Figure 2 shows the experimental arrangement inside the test cell. Cables to be burned were supported in an expanded metal tray located one foot below a suspended steel ceiling which in turn was one foot below the steel compartment overhead. Three water-cooled load cells support the cable tray on a pipe scaffolding so that burning rates can be monitored

by the weight loss. Because surplus cable scraps were used, the description of the fuel elements is limited to the obvious physical properties. Most of the cables were about one inch O.D., insulated with some type of rubber, contained 16 unshielded copper leads and no external armor. A few pieces of polyethylene coaxial cable (½" O.D. and 1" O.D.) were included in some of the fires but by weight, rubber was the principle fuel. Table 1 lists the fuel combinations for the various fires, the number of layers, and the spacings both between cables in a layer and between layers. These spacings are only approximate because the cables were not clamped to maintain the spacing or hold them straight. When it became apparent that the cable fires would not propagate horizontally without assistance, the cable arrays were laid on top of wood cribs as indicated in Table 1.

Forced ventilation at rates ranging from 350 to 1300 CFM was provided by a blower attached to duct 8 in Figure 2. This air entered the iron box at the southeast corner and left through hatch 2 or ducts 6 or 7 corresponding respectively to ventilation patterns G, B, and A. Free ventilation with the blower secured and the fire serving as its own air pump followed two patterns. Air could enter through duct 8 and exit overhead through vent (2) or the door (14) could be opened various amounts to let air flow both in and out. Vent (2) could be opened any amount to a maximum of 18" x 22".

The remaining controlled variable, water spray, was applied by nozzle (9) in the southwest corner of the compartment. Table 1 lists the type of nozzles used in the various extinguishment exercises along with the amounts of water applied. Water was pumped to the nozzles from a 200 gal supply tank equipped with a water level gage that indicated the amount of water used.

2.2 Instrumentation to monitor the uncontrolled variables.

Figure 2 shows the location of the instrument tree used to monitor heat flux, gas temperatures and smoke density. Details of the tree's construction are indicated in Figure 3 along with the pertinent dimensions. The radiometers are mounted in pairs, one bare to measure the total thermal flux and one behind a sapphire window to detect only the radiation

component of the flux when the water-cooled douser is opened. Five photocell and lamp combinations monitor the optical density of the smoke at the locations indicated. Hoods over the lamps and photocells combined with air flowing out of the optical windows protect the elements from smoke deposits and the fire suppression water. Thermocouples on each limb of the tree monitor the gas temperature at that elevation. Three additional thermocouples were mounted in 3/4" stainless steel tubes which in turn were located at 2 ft intervals along the 6 ft cable pile to monitor the rate of fire spread and tempratures in the fuel bed. Figure 2 shows the identification numbers assigned to each sensor, i.e., radiometers R_1 through R_6, T.C. 1 through 9 and photocells P.C. 1 through 5. Thermocouple 6 monitored the exit air temperature at the entrance of duct 6 or 7. Sample tubes in the exhaust ducts (10) provide the gas for CO_2, CO, O_2, and hydrocarbon analysis. An additional port in the exhaust duct was used with Dräger tubes to check for HCℓ. All electronic signals were recorded with a Hewlett-Packard 3052A data acquisition systems which sampled 23 channels of information every 4 to 5 seconds.

2.3 Procedures and Rituals

After the controlled parameters for a test were set at the values listed in Table 1, the fire was initiated with burning ethanol from a saturated M-board wick contained in the stainless steel pan (item 16 in Figure 2) which in turn was supported on a movable arm that could carry the fire from one end of the cable tray to the other. The ritual followed after ignition depended on the emphasis of the particular tests. Initially, i.e., tests 7 through 12, the emphasis was on the burning characteristics, particularly flame spread and the requirements for a vigorous fire. These fires were allowed to pass the peak burning rate before the ventilation pattern was changed by opening the overhead hatch and the extinguishment exercise came last. Typically, these fires burned 40 to 60 min before being extinguished. From test 6 on, more attention was given to smoke removal, e.g., by vertical ventilation versus horizontal ventilation. Also, a variety of water spray conditions were used as indicated in Table 1. With ventilation patterns A and B, the fires

generated relatively little smoke, therefore, water spray was used to fill the compartment with smoke just before the ventilation exercise. The char on the rubber cables in addition to the shielding from multiple layers of cables prevented complete extingishment with modest amounts of water; therefore, the fires were allowed to recover and two suppression tests and smoke removal exercises could be conducted on one bundle of cables. Table 1 lists the point of emphasis for each test along with the ritual followed in smoke removal and suppression.

3.0 Results

3.1 Cable fire characteristics

Under the test conditions listed in Table 1, the cable fires exhibited the following characteristics:

- Without thermal reinforcement from other burning fuels, the flames did not propagate along the cables in the horizontal direction. For example, in tests 7, 8, and 10, the cables burned only above the ignitor pan. Only a small fraction of the available fuel burned.
- With ventilation pattern B, a layer of smoke and vitiated air collected around the cables and reduced the burning rate both in the presence and absence of thermal reinforcement from a wood crib.
- With ventilation patterns A and G, flame spread and complete combustion could be obtained when the cables were burned on top of wood cribs. Under such conditions, the burning rates for the largest fires were 10 to 12 g sec^{-1} while the crib was making a major contribution to the weight loss and substantially less when the wood was mostly gone.
- Air temperatures inside the iron box remained at moderate levels. For example, in one of the hottest fires, the air temperatures at the instrument tree location remained below 250°C as shown in Figure 4a. Near the deck the temperatures were less than 100°C. The sharp temperature changes at 1500 and 3960 sec were caused by the water sprayed on the fire; however, the top thermocouple had reached its peak both times before the water arrived. Figure 4b shows the corresponding air temperature measurements for ventilation pattern B fires where peak temperatures are less than 150°C and unprotected firemen could tolerate the temperatures near the deck.

- Smoke did not obscure the fires during the unperturbed portion of the tests. Two smoke situations were examined (1) the quasi steady state fire where the smoke distribution is relatively constant and (2) the extremely transient conditions associated with extinguishment. In the first case, buoyancy confines the smoke to the upper part of the compartment. Even with ventilation pattern B, most of the obscuration remained above P.C. 3, i.e., in the top 2 or 3 feet. At all times during the unperturbed burning period for all three ventilation patterns, the flames were readily observed through the window (item 12 in Figure 2). With ventilation patterns A and G, the smoke layer floated mostly in the top 2 feet of the box. In the second case, i.e., when water is sprayed on the fire, smoke, pyrolysis products, and steam quickly fill the entire box and visibility drops to near zero. Figure 5 for the photo cells in test 14 illustrate this abrupt change in visibility which also was verified by observations through the window.

- Maximum values of the oxygen depletion and combustion product production are tabulated in Table II. At the lower ventilation rates, the exhaust gases contained about 5% CO_2, 0.6 to 0.9% CO, 15% O_2 and a trace of unburned hyrocarbon. When PVC coatings were burned on the coaxial cables, HCℓ was detected with the Drager tubes; however, the HCℓ observations remain qualitative due to uncertainties regarding the effects of gas temperature on the calibrations. During the transient condition when water is sprayed on the fire, the oxygen consumption drops abruptly and CO_2 and CO production decrease correspondingly, i.e., the water has terminated most of the combustion. A superpositioning of a weight loss curve Figure 6, the smoke obscuration curve Figure 5, and gas concentration curves Figure / illustrate the timing for cessation of combustion and production of smoke associated with the application of water. After ventilation and recovery of burning, the combustion products reappear although their magnitude indicates the fire is not burning with the vigor exhibited prior to the first water application.

3.2 Smoke Ventilation

Three ventilation situations were explored.

- Smoke control during the quasi steady state burning versus the transient conditions associated with suppression.

- The ventilation driving force i.e., natural buoyancy versus forced ventilation.

- The ventilation pattern i.e., vertical versus horizontal flow paths.

In the quasi steady state fires, the ventilation requirements were not severe; e.g., patterns A and G with both forced and natural ventilation were quite adequate to confine the smoke to the top of the chamber. The suppressed fires were the most challenging. After the lamps on the instrument tree were equipped with hoods, the photo cells could monitor visibility throughout the water spray and smoke clearance operations.

Figure 5 shows the response of the five photo-cells during test 14 where forced and natural ventilation are compared for ventilation pattern A + G. At 18 min 23 sec, ten gal of water were applied to the fire and all of the photo-cell signals dropped preciptously as the lower regions of the chamber filled with smoke and steam. At 21 min, the 2.75 ft^2 overhead hatch was opened to produce ventilation pattern A + G and the air inlet rate was increased by a factor of about 3. In about one minute, visibility was restored to the bottom part of the chamber. After the fire had recovered, another 10 gal of water was applied at 38 min and 37 sec and again the photo-cell signals plummeted because of the smoke and steam. At 40 min 14 sec the door was opened to provide a one foot wide crack and the forced ventilation was secured. Again, the visibility was restored promptly (i.e., within 2 min); however, much of the smoke escaped through the top part of the door opening. Figure 8 shows a similar comparison for vertical versus horizontal exhaust patterns. Actually the vertical pattern was a combination of A + G because there was no damper in the duct 7; however, with the overhead hatch open, most of the smoke left by that path. Because the blower controlled the rate which was the same in both cases, the times to clear the chamber were quite similar for the two patterns.

Figure 9 illustrates the effect of the water spray on the thermal insult experienced by the radiometers 8½ feet below the overhead. R_3 is the radiometer with a sapphire window located behind a watercooled douser. When the douser is opened, R_3 registers the incoming thermal radiation in contrast to R_4 which is bare and therefore, sensitive to the total incident thermal flux. When the water is applied to the fire, R_3 signals a reduction in the thermal radiation whereas the R_4 signal drops momentarily, then increases significantly indicating a greater thermal input. Because

R_3 shows a decrease in the radiation level, the R_4 increase must be due to convective heating either from hot gases or steam. Figure 10 shows the corresponding thermocouple signals from the instrument tree. All of the temperatures drop abruptly at 25 min indicating a cooling of the gas temperatures; therefore, it appears the increased radiometers signal from R_4 arises from an increase in the heat transfer coefficient, not the temperature; e.g., steam could have such an effect. This radiometer behavior was observed repeatedly in this test series. This transient thermal insult is not large but neither is the overhead temperature. In a very hot compartment such as under flashover conditions, a similar water spray could generate superheated steam and a much greater insult. The various water spray arrangements did not alter the transient thermal insult significantly.

4.0 Discussion

4.1 Cable fire characteristics

The cable fires presented only a modest thermal threat. Without assis*nace from other fuels, i.e., the wood cribs in these burns, the flames would not spread over the 6 ft length of the cables when ignited at one end. This behavior is in agreement with the results of other observers who find that cables in single trays frequently do not propagate fires effectively in a horizontal direction. Multiple layers of trays or vertical runs are required for rapid spread. Our burning rates of 10 to 12 g sec^{-1} are comparable to burning rates observed in Reference 1 where wood and rubber tire fires were well below the flashover range. The air temperature and thermal flux measurements listed in Table 2 indicate that these cable fires were also well below any flashover condition.

4.2 To ventilate or seal a compartment, that is the question

Reference 2 discusses this question based on observations of fire behavior in sealed and forced ventilation compartments. Here we summarize these thoughts and apply the concepts to a real fire situation. The first

step is to understand why we seal or ventilate a compartment fire.

- Why ventilate?
  - Aid in search and rescue operatons by removing heat and toxic products and by maintaining visibility.
  - Prevent or reduce fire spread caused by the hot gases and combustion products trapped under the overhead
  - Reduce the possibility of flashbacks or smoke explosions
  - Assist firemen to reach the fire by removing the heat and smoke that often keeps them at bay.
- Why seal?
  - Cause the fire to extinguish itself
  - Confine the smoke and other combustion products
  - Limit burning and damage while the firemen are preparing to extinguish the fire.

All of the what, when, where, and how questions that follow are concerned with optimizing the why answers. Obviously, there are many fires where the whys do not apply and there is no reason to decide between ventilation and sealing. Fortunately, most ship fires are controlled before they develop into a serious threat. Only about 5% of the fires cause major damage (a loss greater than $100,000 or loss of life) and require extensive fire suppression efforts. When these large fires occur, the next step is to evaluate the available options to see if sealing or ventilating will assist in controlling the fire. A variety of information is needed to make this evaluation.

- What is the state of the fire and what will control the ultimate fire size and intensity? Fires grow in size and intensity until the lack of additional fuel, heat feedback, or ventilation establishes an upper limit to the fire size. If the available fuel surface is controlling the burning rate e.g., bilge fire, additional air will not increase the fire size and ventilation can be used to remove smoke and heat without fear of increasing the fire threat. When the fire size is ventilation controlled e.g., a storeroom fire, additional ventilation will obviously intensify the fire and the firemen must be prepared to achieve control before this additional threat can nullify any advantage gained from the removal of heat and smoke. If not suppressed, most ship compartment fires will grow until their size is ventilation controlled.

- What are the opportunities for controlling or smothering the fire by sealing. In existing Navy ships, few compartments are both gas tight and small enough to smother a fire, particularly before it can cause serious damage. The space between fire control bulkheads is too large for the smother approach except as a last resort when the suppression efforts cannot confine the fire to the smaller subdivisions.
- What ventilation paths are available?
  - Vertical
  - Horizontal
  - Combinations of vertical and horizontal

Several factors to be considered in selecting a ventilation pattern are: (1) safety, the ability to remove combustible vapors and smoke before incoming fresh air can create an explosion or flashback, (2) efficiency, usually the shortest path will be most effective, and (3) loss minimization, keep the exhaust path away from areas that are critical either because of their value to the ship or their potential to contribute to the fire damage, e.g., munitions.

- What force will drive the ventilation?
  - Buoyancy of the heated gases, i.e., the fire serves as its own pump. This force is particularly effective with vertical paths
  - The wind either natural breezes or the breeze created by a ship's motion
  - Forced ventilation with fans or smoke ejectors.

Reference 2 notes that "the question of where and how to ventilate a compartment is frequently compounded by the difficulty in obtaining all the desirable information about fuel loadings, potential fire sizes, normal ventilation and available ventilation paths under the stress and confusion of a fire. Consequently, the decision to ventilate or seal a particular compartment should be made as part of a pre-fire plan. Where ventilation is in order, the path should be laid out so there is no uncertainty during a fire. This pre-fire planning should consider the ventilation goals and the factors affecting the potential for success. Also, other options for achieving the same goals should receive attention. For example, it may be more practical to equip some compartments with

septums overhead or in the deck where nozzles can be inserted." Preferably such fire protection plans should evolve during the design of a ship when modifications in the ship could be made to circumvent, particularly awkward fire problems. At the least, sealing and ventilation plans should be incorporated in the ship's damage control plans.

4.3 Application of sealing and ventilation concepts to the Iwo Jima fire of July 1974.

At the time of the fire the Iwo Jima was moored on the north side of pier 25 at the Norfolk Naval Base. Winds variable from the west and gusting to 25 mph would impinge on the stern of the ship. The fire, apparently incendiarism, was set in a berthing space (01-131-0L) between the sick-bay and the fantail. A plentiful supply of class A fuel was present in the foam rubber mattresses encased in cotton ticking and naugahyde envelopes. The large compartment occupied the entire space athwart ship, between the port and starboard passageways. A two inch and greater gap between the top of the interior bulkheads and the overhead permitted smoke and combustion products to spread into all the surrounding medical compartments and prevented isolating or sealing the burning compartment. The final losses exceeded a million dollars so this was not a trivial fire where the question of sealing or venting could be ignored. An examination of the options shows that sealing was impossible and venting would be difficult. The first arriving fire parties were held back by heat and smoke and there was a definite need to remove these barriers so the firemen could reach and attack the fire, i.e., the "why" reason. In considering the possible ventilation paths, we have used arrangement sketches that may not show all the hatches but it appears that no hatches are available going up through the gallery deck and flight deck above the fire compartment. On the gallery deck, the balloon inflation room, meteorological office and helium storage rooms are located above the burning compartment. Any of these rooms could be sacrificed as an exhaust chamber considering the emergency; however, two holes would have to be cut to reach topside. Several horizontal paths are available, e.g., through the passageway to the hangar or through a hole cut in the fantail exterior bulkhead. This fantail hole is the most attractive from an efficiency standpoint because the path is short, direct, and does not pass through any valuable real

estate, namely the medical space. However, the wind incident on stern would make forced ventilation necessary to keep from driving the smoke through the ship. Fire parties could attack from the passageway or up through a hatch from the main deck into the fire room. Finally, the other options should be considered. Handlines were brought into the Meterological office and a living space across the transverse passageway to cool the decks above the fire. If these compartments had been equipped with septums in the decks, celler type nozzles could have been used to control and suppress the fire from above without having to battle the smoke. In view of the cable fire tests and the JBISS exercises, this septum approach appears the most desirable for a fire in the berthing space that burned.

5.0 Conclusions

This year efforts focused on smoke control in cable fires. Consequently, the experimental variables were limited to (a) one type of fuel and its arrangement and (b) one arrangement for extemporaneous ventilation. Aboard ship, cable fires cause considerable damage because ship functions and weapon systems are interrupted but the thermal threat from a horizontal cable bundle appears to be relatively modest. Because of the slow flame spread rate the fires were fuel surface controlled and the mode and quantity of forced ventilation had little effect on the thermal insult.

Smoke control by an extemporaneous hole opened directly above the fire (Pattern G) was very effective in clearing the compartment; however, it should be emphasized that this ideal ventilation pattern is seldom available in ship compartments. These observations need to be extended to other combinations of the experimental variables capable of generating a severe thermal environment under ventilation conditions simulating ship compartments where smoke control would be much more difficult than with Pattern G.

6.0 Future Work

In view of the current interest in the role of smoke and heat control in supporting manual firefighting on shipboard, it appears desirable to emphasize the features of the fire environment that control when, where, and how fire ventilation should be used to assist firemen in their attack. The temporal and spatial characteristics of the compartment fires should be measured under other condtions of normal forced ventilation and ventilation from extemporaneous holes. Particular emphasis should be placed on fires capable of a more serious thermal threat than the present cable fires. Both the smoke generation and the thermal threat induced by suppression efforts should continue to be examined.

REFERENCES

1. R. S. Alger, et al., "Ship Fire Characteristics, Part 1, Sealed Compartments," NSWC TR 1976.

2. R. S. Alger, et al., "Ship Fire Characteristics, Part 2, Forced Ventilation Controlled Fires," Prepared for the Naval Research Laboratory by SRI International on PYU 8479 (April 1980).

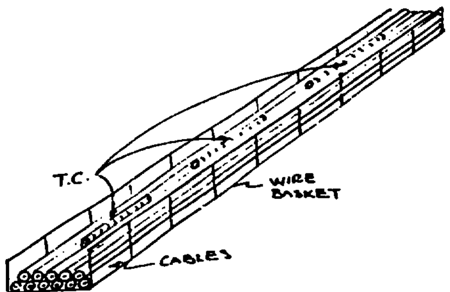
Table 1

EXPERIMENTAL CONDITIONS FOR CABLE FIRE TESTS

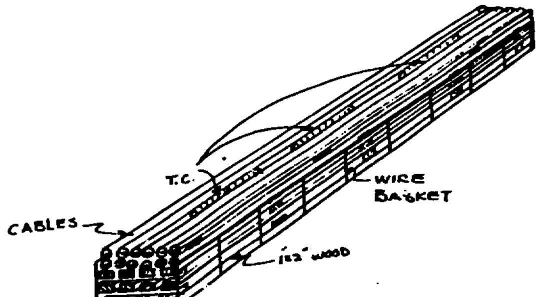
	Fuel				Ventilation							Water Spray				Main Emphasis of Tests
No.	1" O.D. Rubber Covered Cable lbs	½" O.D. Poly-ethylene Insulated Coaxial lbs	1" O.D. Poly-ethylene Insulated Coaxial lbs	Wood Cribs lbs	Forced Rate,Patt	Pattern for 1st Smoke Removal	Time	Time to Clear T min	Pattern for 2nd Smoke Removal	Time	Time to Clear min	Nozzle No	Nozzle Type	Water 1st Gal	Applied 2nd Gal	
7	60.5				720 B	B+G	51' 32"	(5)	None			1	Navy	30		Fire characteristics - fire spread in cables
8	61		30		720 B	B+G[4]	47' 27"	2	None			1	Navy	30		Fire characteristics - enhancing fire spread
9	40		20	30	720 B	B+G[4]	10' 56"	(5)	None			1	Navy	30		Complete cable involvement
10	60	6			720 A	A+G[4]	40'	~ 1	None			1	Navy	30		Effect of ventilation pattern on burning rate
11	60	7		28	720 A	A+G[4]	25' 29"	(5)	None			1	Navy	30		Complete cable involvement fire characteristics
12	~ 64			27.5	350 A	A+G	63' 54"	~ 3	None			3	Small	30	10	Increase smoke for ventilation exercise
13	64			~ 27	350 A	A+G	28' 5"	3.5	A+G	59' 57"	3.5	3	Medium	30	10	Effect of nozzles on thermal insult at bottom of compartment
14*	62			27	350 A	A+G[1]	21'	1	A+G[2]	40' 14"	1.5	3	Medium	10	10	Obscuration during water spray and time to remove smoke
15	60			25.5	350 A	A+½G[1]	30' 27"	4	A[3]	~ 66'	3	3	Medium	10	10	Repeat of 14 with G opened ¼ way
16	60			37	350 A	A+G[1]	34' 44"	2	A[1]	55' 22"	4	3	Small	10	10	Buoyancy ventilation and compare vertical to horizontal patterns
17	60			34.5	350 A	A+G[1]	28' 50"	1	A[1]	42' 52"	2	1	Large	10	10	Compare vertical to horizontal pattern

*Starting with Test 14, recorded smoke and steam obscuration during water spray

(1) Blower up to 1300 CFM during smoke removal
(2) Opened door ~ 1" to assist in smoke removal with blower secured
(3) Fire dying down, not much smoke
(4) Ventilated before sprayed water; all other tests vented after water spray
(5) Not enough smoke left to measure.



Test 7,8



TESTS 9—17

Table 2

MAXIMUM VALUES OF MEASURED PARAMETERS

Test No	Time First Water Applied t_w	Weight Loss to Time t_w k.g.	Exit Gas Temp oC	O_2 %	O_2 Time of Max	CO_2 %	CO_2 Time of Max	CO %	CO Time of Max min	Temperature in Cable Bundle West °C	Midd °C	East °C	R_1	R_2	R_3	R_4	R_5	R_6	Time Test Terminated
7	~60'	1.1	33.5	—	—	—	—	—	—	560	150	140	—	.15	.5	>.5	—	—	62' 67"
8	53' 17"	2.8	33	.42	54	1.6	26	.17	26	640	595	717	1	.6	1.3	.2	.1	1.2	59' 20"
9	40' 45"	19	44.4	—	—	1.5	6	.19	6	670	850	920	.5	.9	.3	.5	.2	.2	~40' 45"
10	46' 20"	3.2	120	.44	10	.3	9	.38	20	580	120	120	.1	.2	.1	.1	—	.1	46' 20"
11	39'	22	235	—	—	14	17	.7	23	700	415	785	.26	.6	.2	.5	.2	.2	56' 56"
12	22' 2"	11.2	204	6.5	14	4.6	14	.88	14	850	530	750	.1	.6	.1	.3	.2	.3	68' 39"
13	22' 23"	12	200	4.9	22	3.8	8	.58	12	387	400	457	.1	.6	.1	.6	.2	.4	60' 56"
14	18' 23"	6.4	212	6.9	15	5	12	.88	15	510	—	720	.1	.8	.2	.3	.3	.5	43' 20"
15	25' 5"	16	229	5.8	4	3.9	4	.55	4	590	650	580	.1	.8	.3	.4	.1	.3	66' 30"
16	30' 55"	21	233	6.8	5.6	5.1	5.6	.93	5.6	540	580	390	.1	.7	—	.4	.1	.3	60' 30"
17	25' 13"	20	250	4.9	20	3.4	17	.66	17	460	480	500	.2	.8	—	.7	.4	.5	48'

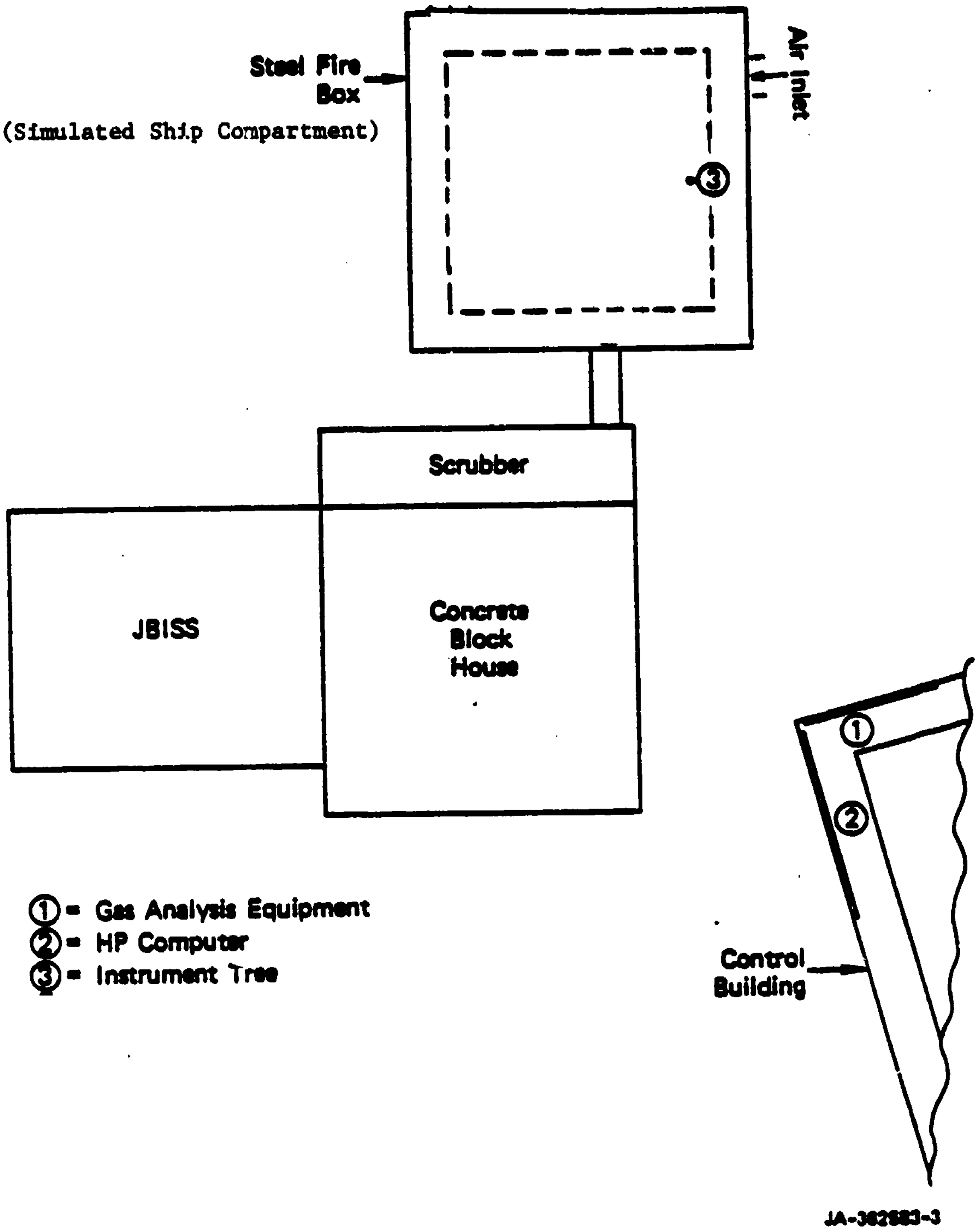
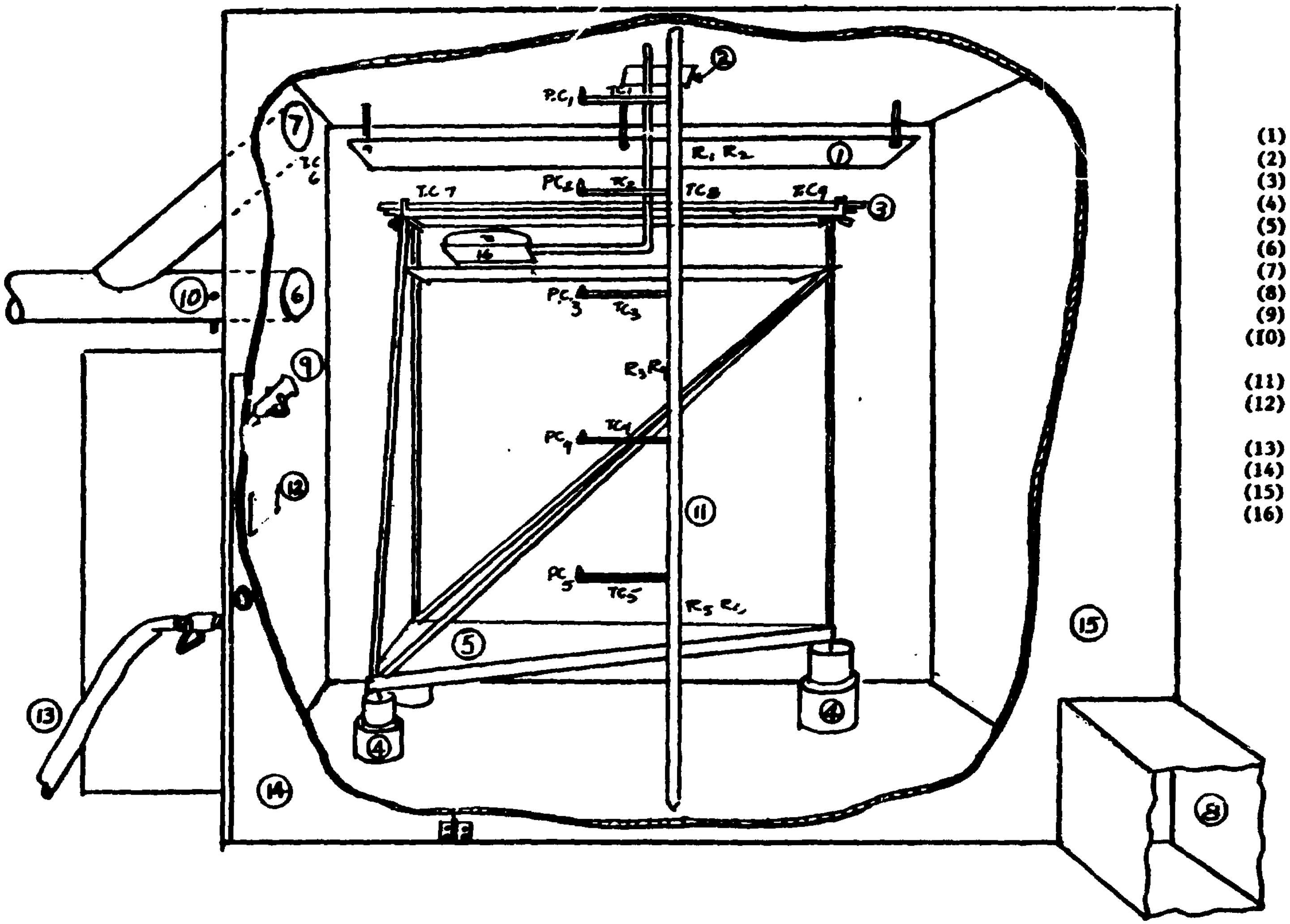
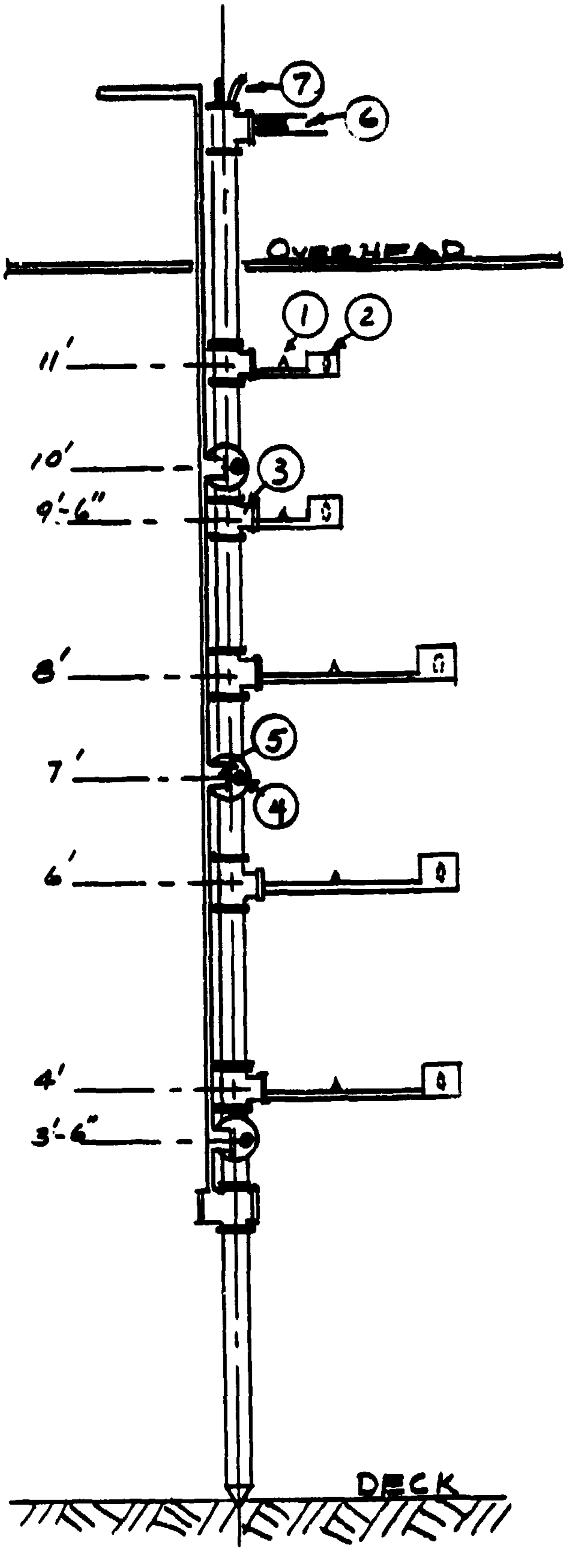


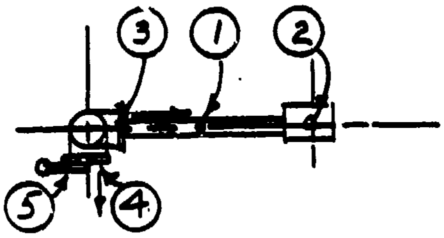
FIGURE 1 PLAN VIEW OF TEST CELLS AT CAMP PARKS



(1) = Drop ceiling
(2) = Vent in overhead Pattern C
(3) = Cable tray
(4) = H_2O cooled load cells
(5) = Load cell platform
(6) = Vent Pattern B
(7) = Vent Pattern A
(8) = Air inlet
(9) = H_2O Nozzle
(10) = Sampling tubes CO_2, CO, O_2 Hydrocarbon, Dräger tubes
(11) = Instrument tree
(12) = Window to observation booth
(13) = Fire hose
(14) = Door
(15) = 12' x 10' x 12' iron box
(16) = Movable ignition pan

FIGURE 2 EXPERIMENTAL ARRANGEMENT AND INSTRUMENTATION IN IRON TEST CELL





1. Thermocouples
2. Tungsten Halogen Lamps
3. Photo Diodes
4. Bare Radiometers
5. Radiometers with Sapphire windows behind water-cooled douser
6. Signal cables
7. Air and water

FIGURE 3 INSTRUMENT TREE

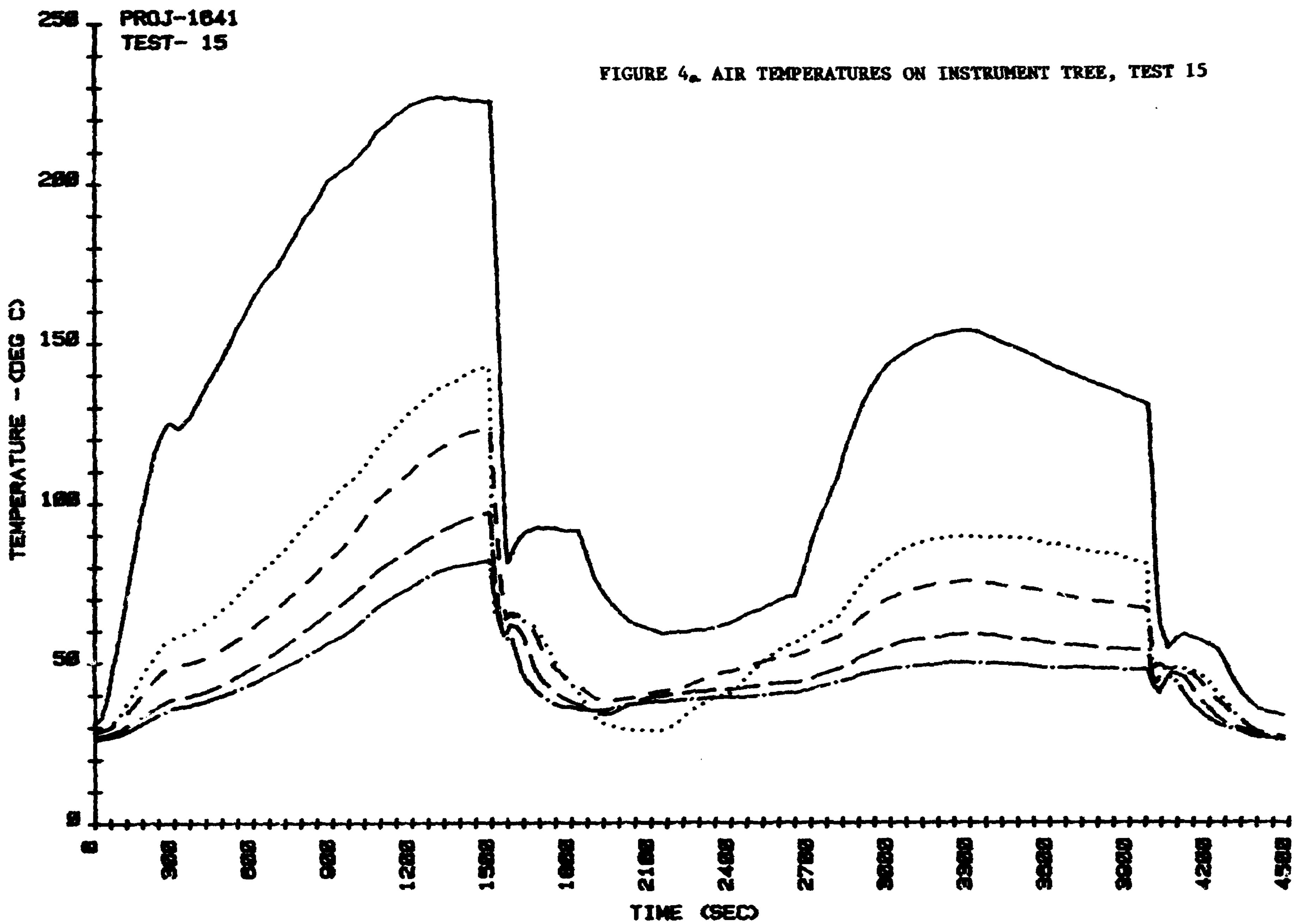
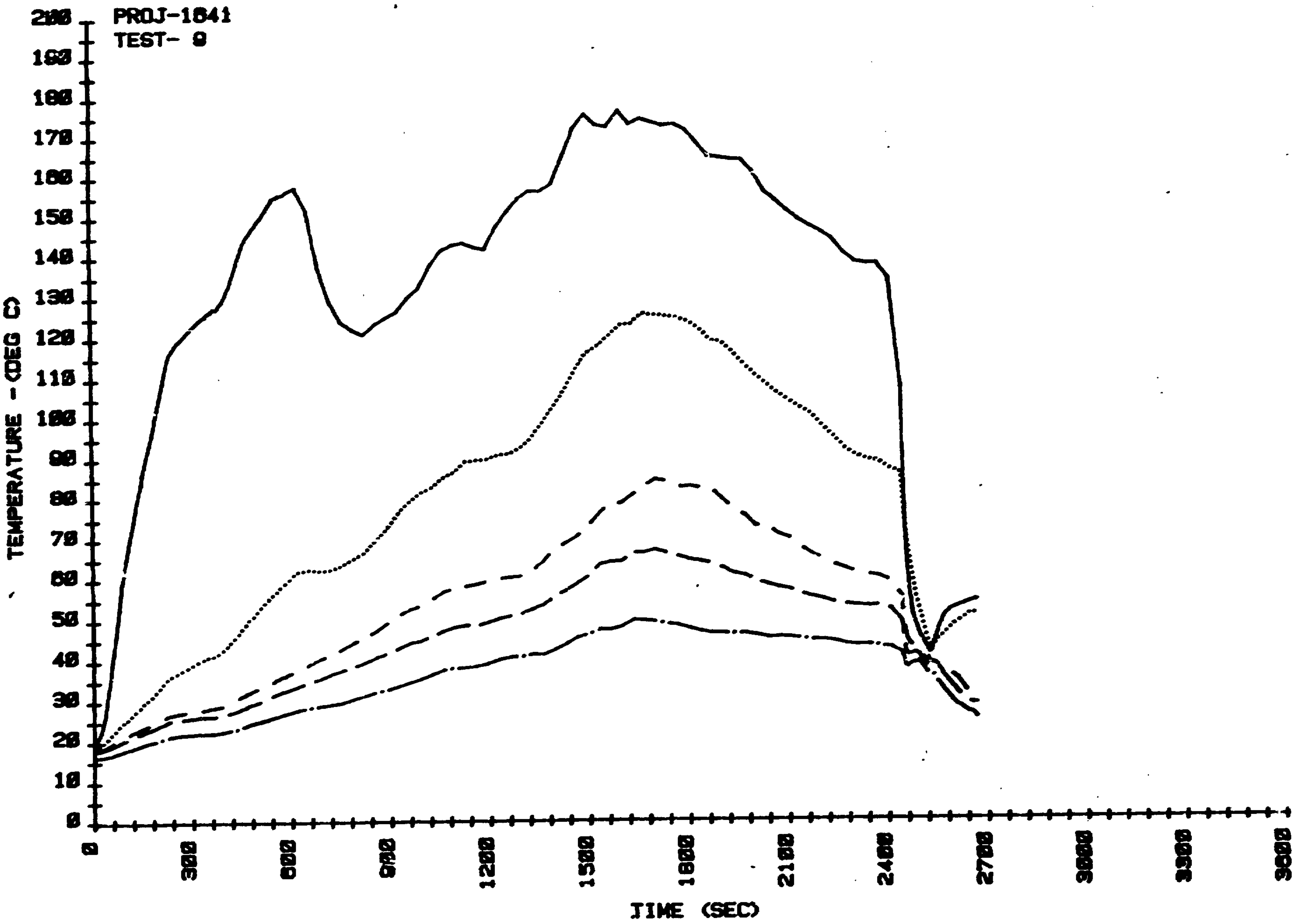


FIGURE 4. AIR TEMPERATURES ON INSTRUMENT TREE, TEST 15

FIGURE 4b AIR TEMPERATURE ON INSTRUMENT TREE, TEST 9



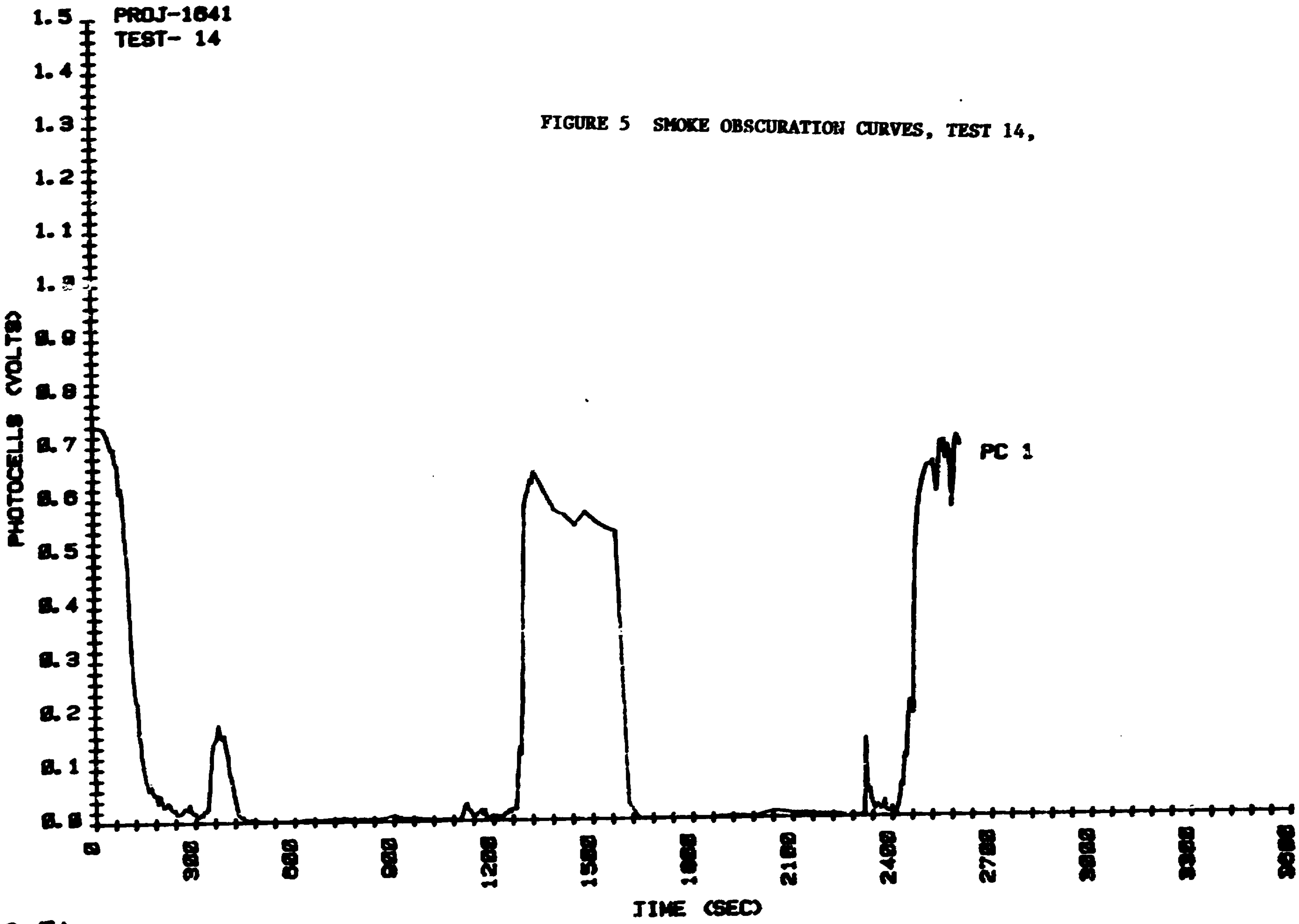


FIGURE 5 SMOKE OBSCURATION CURVES, TEST 14,

FIG 5A

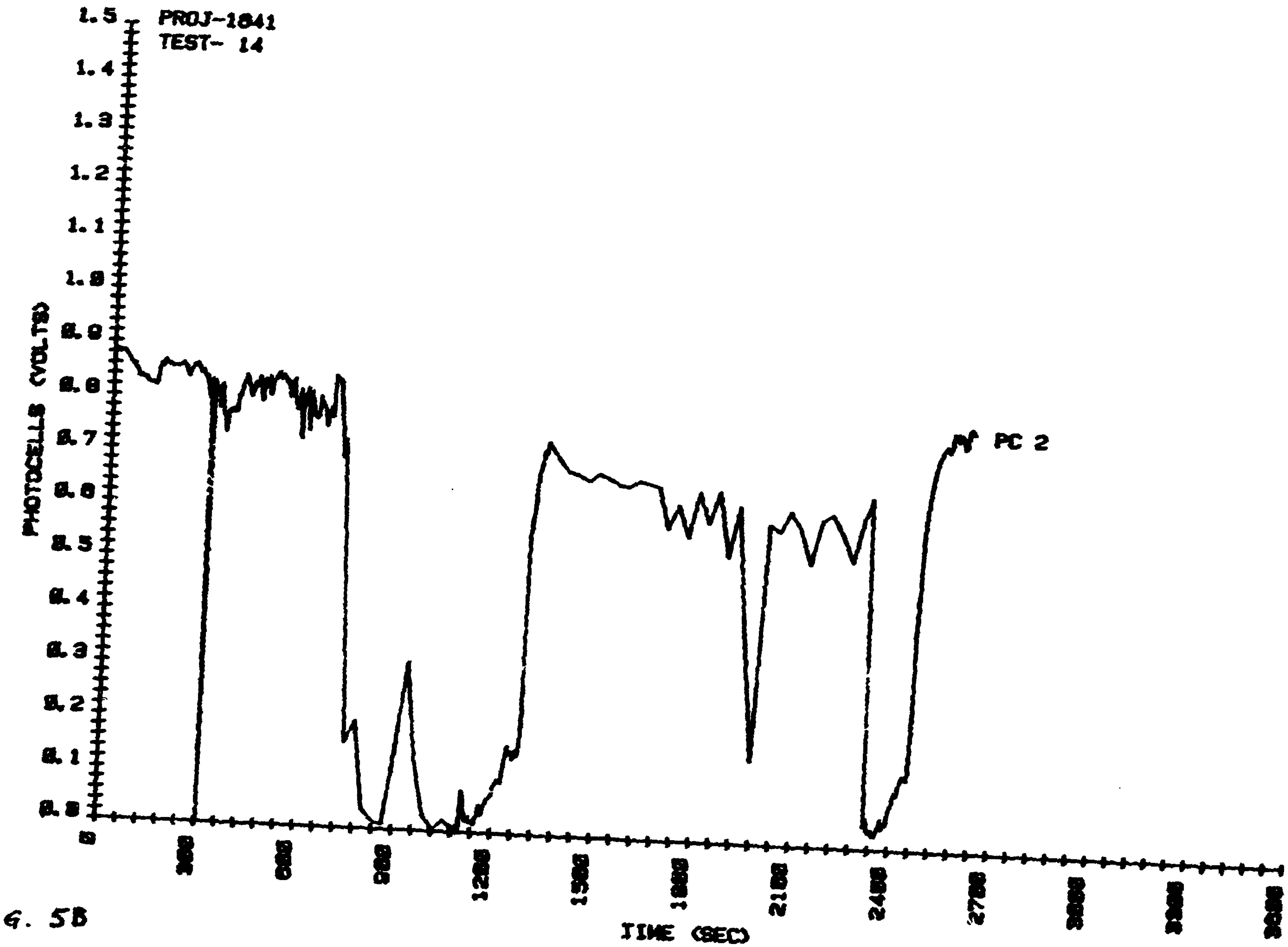

PROJ-1841
TEST- 14
PHOTOCELLS (VOLTS)
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
PC 2
0
300
600
900
1200
1500
1800
2100
2400
2700
3000
3300
3600
TIME (SEC)

FIG. 5B

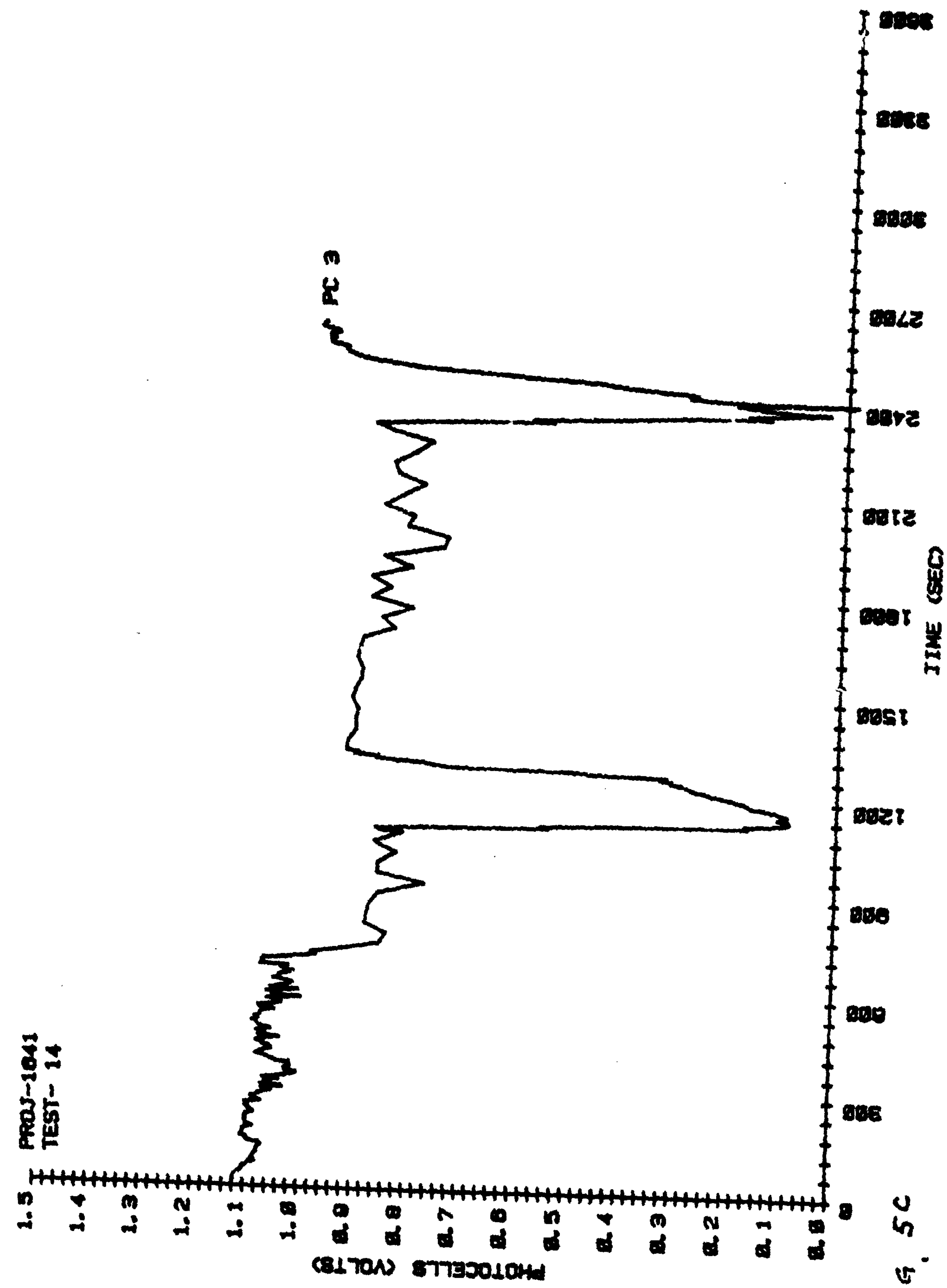


Fig 5C

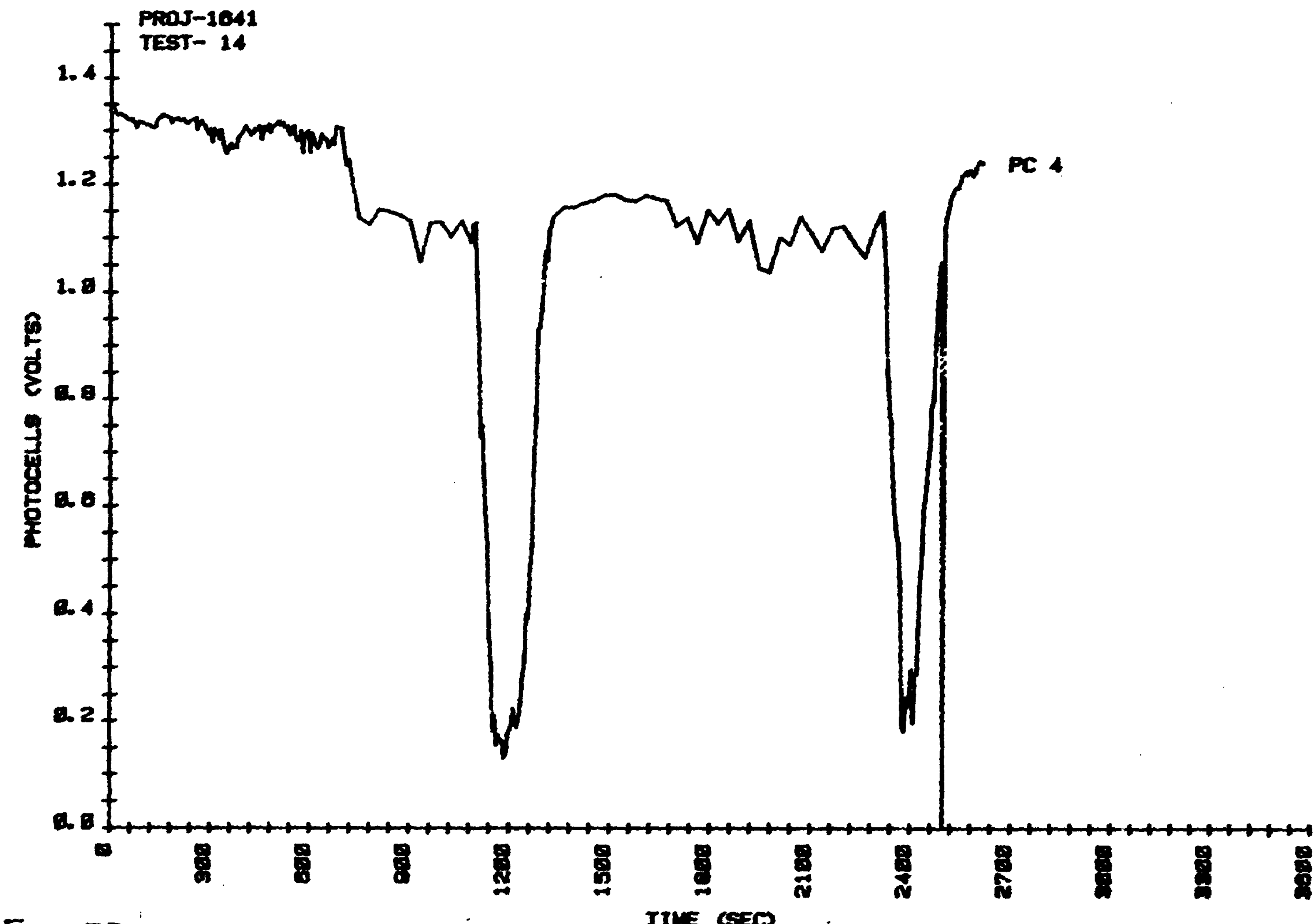

PROJ-1041
TEST- 14
PC 4
PHOTOCELLS (VOLTS)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
300
600
900
1200
1500
1800
2100
2400
2700
3000
3300
3600
TIME (SEC)

Fig. 5D

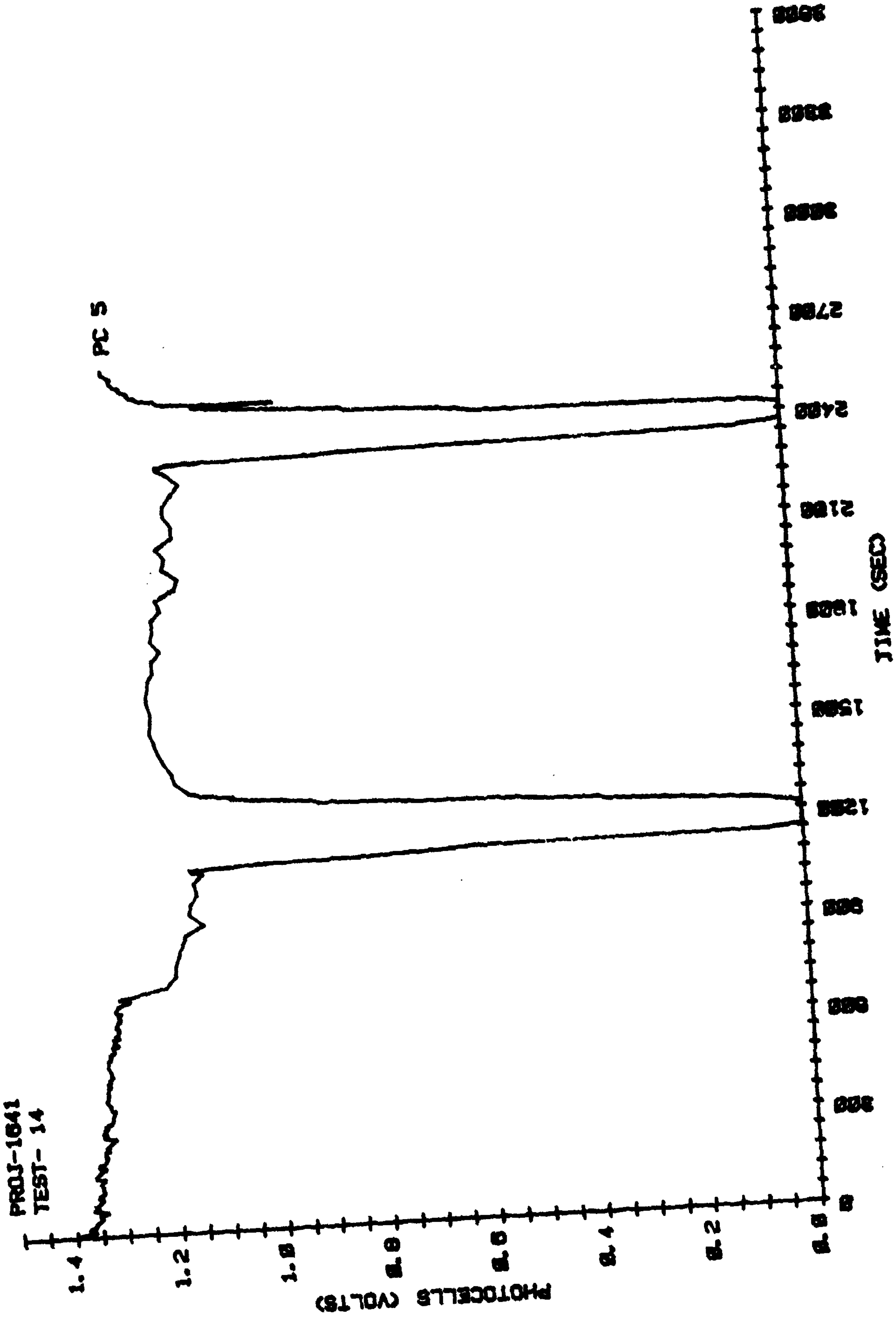

PROJ-1641
TEST- 14
PC 5
TIME (SEC)
PHOTOCELLS (VOLTS)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
300
600
900
1200
1500
1800
2100
2400
2700
3000
3300
3600

FIG. 5E

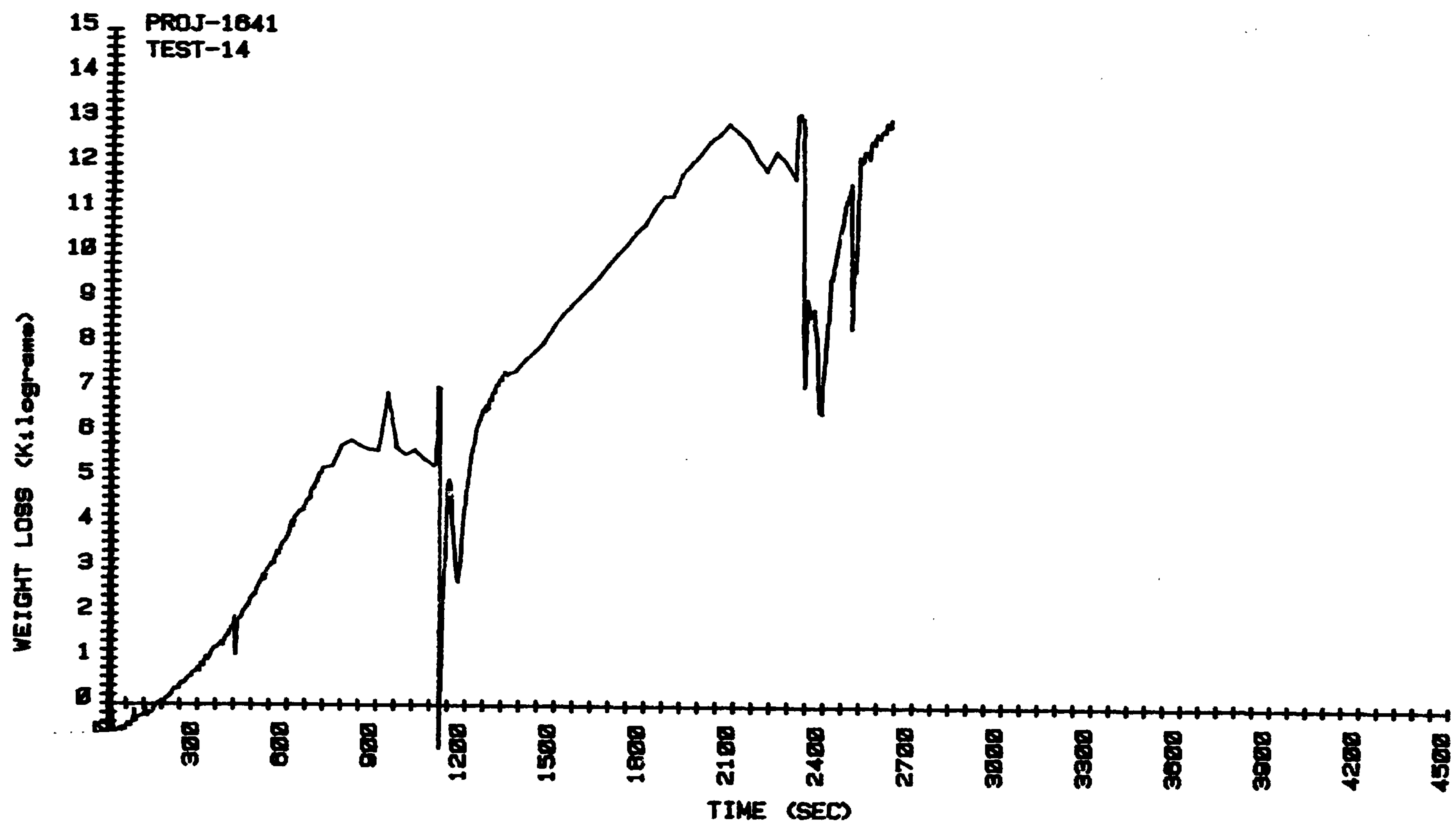


FIGURE 6 WEIGHT LOSS FOR CABLE BURNING ON A WOOD CRIB

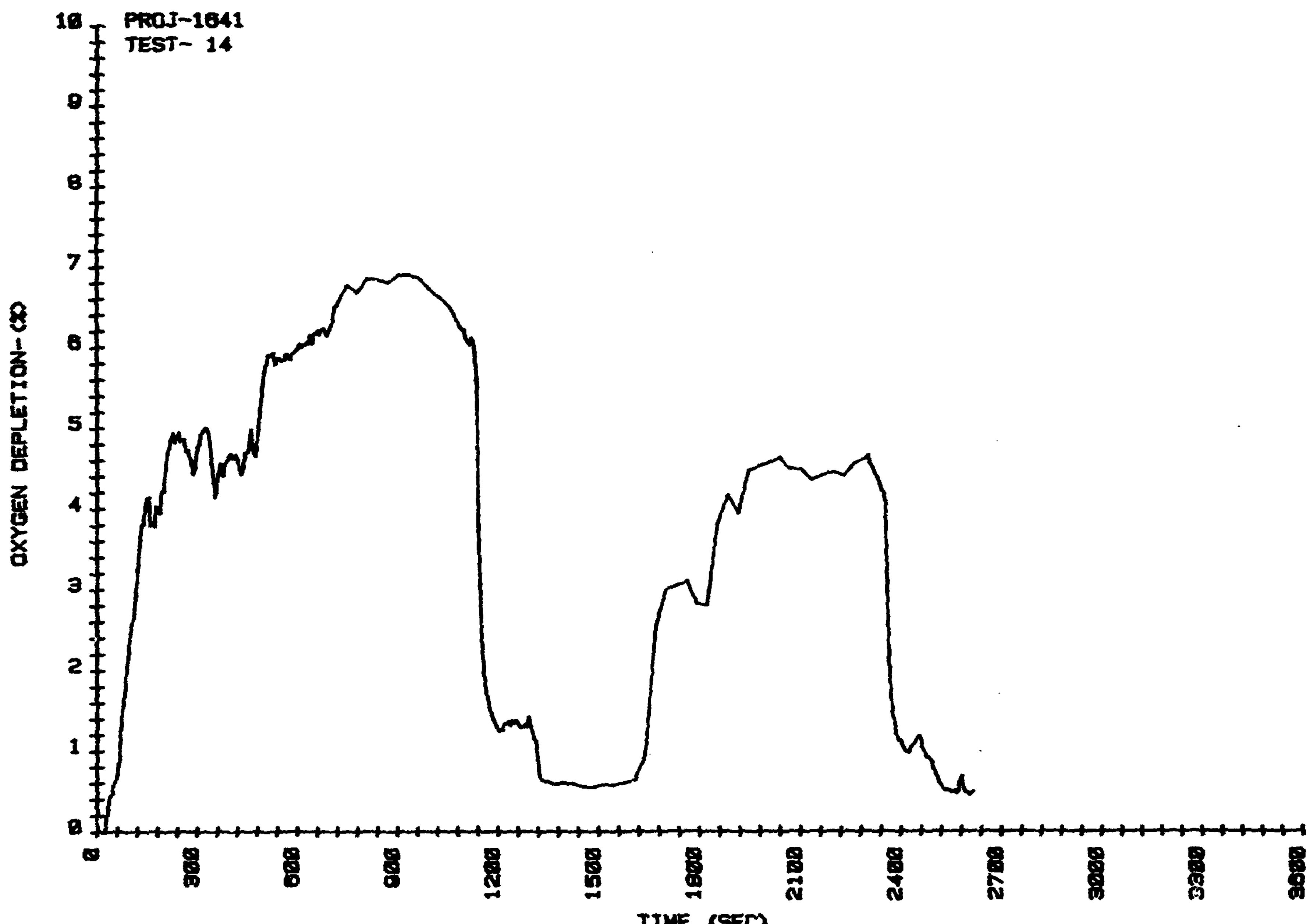


FIGURE 7A O_2 DEPLETION

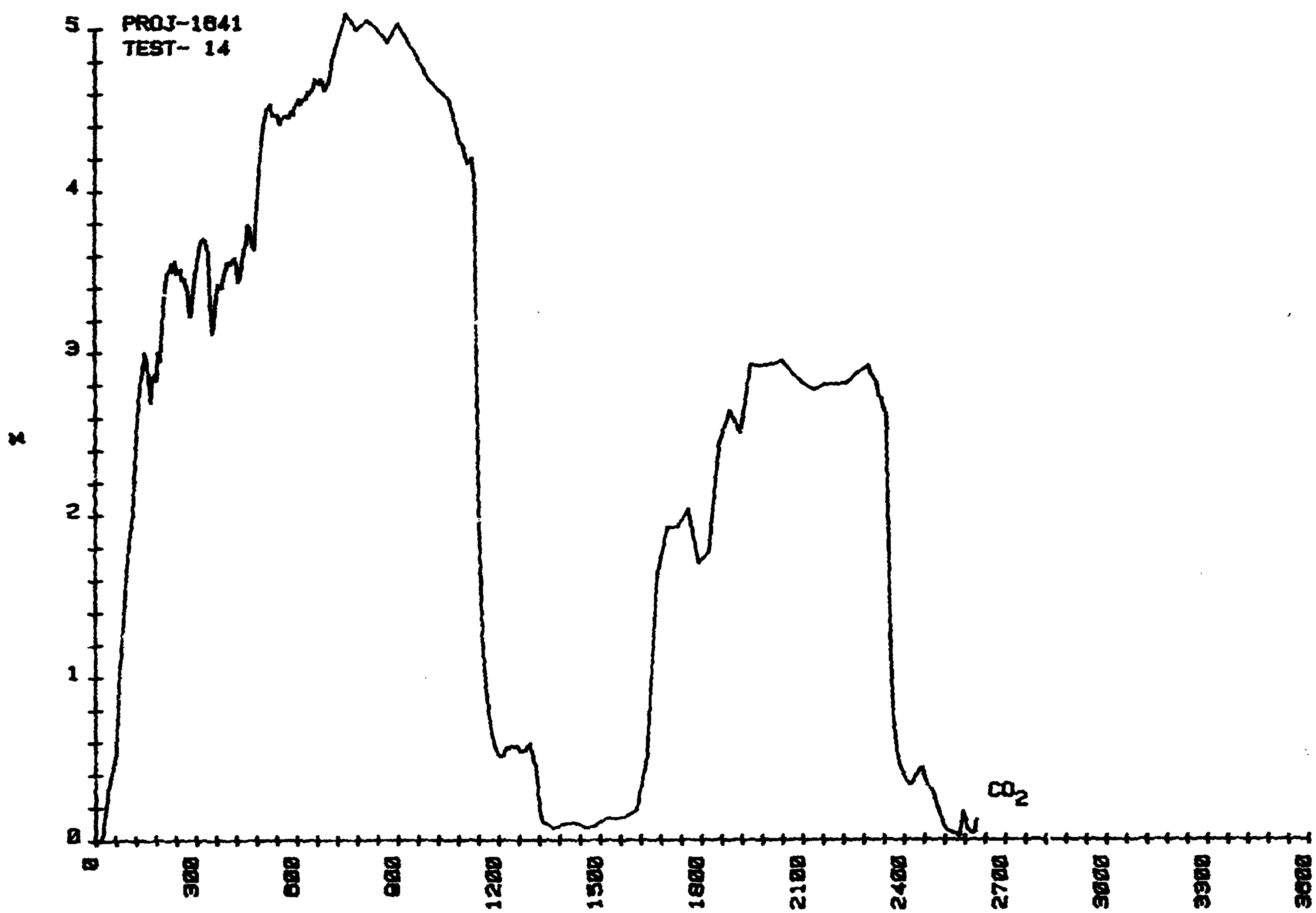


FIGURE 7B CO_2 PRODUCTION

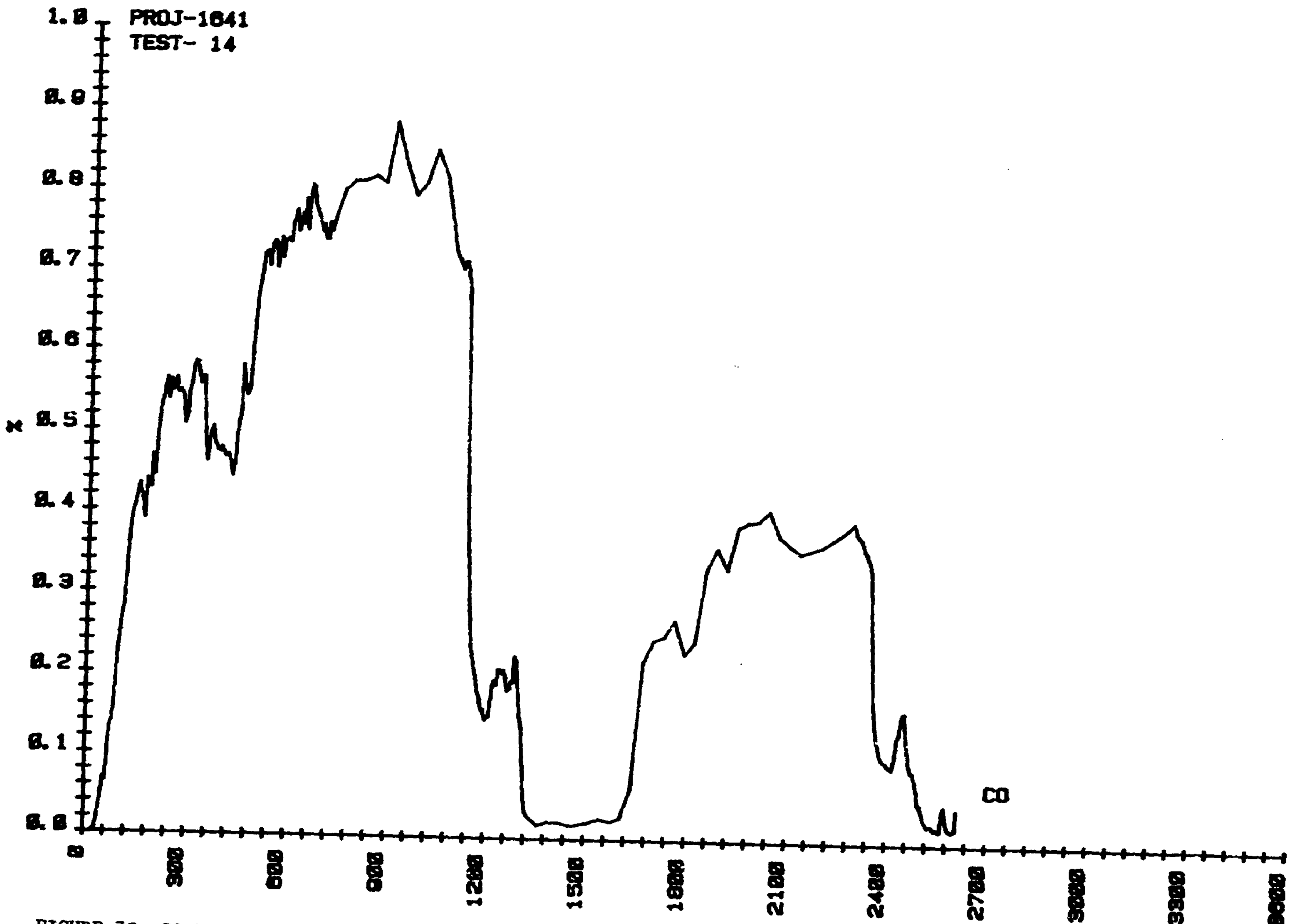


FIGURE 7C CO PRODUCTION

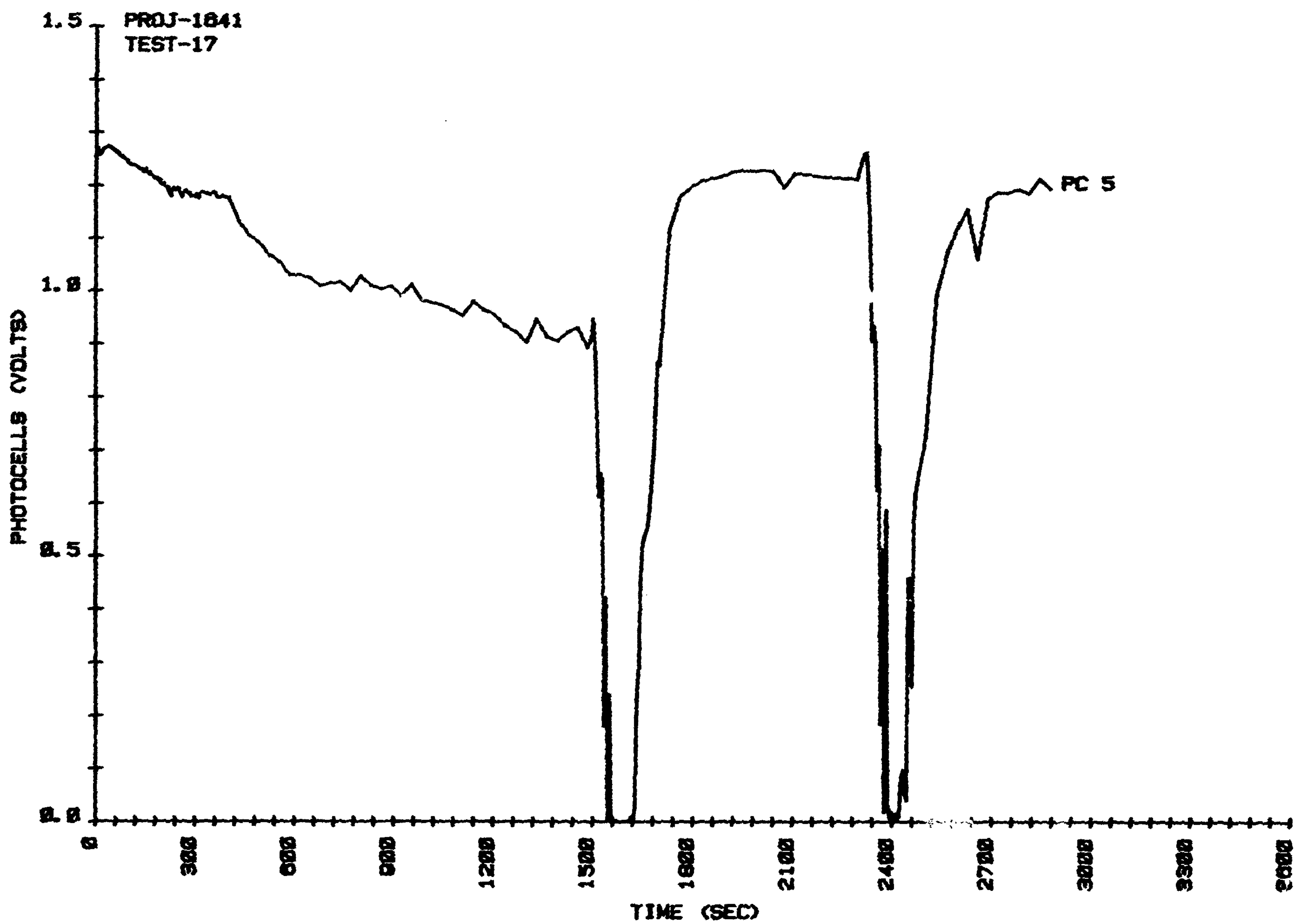


FIGURE 8 SMOKE VENTILATION FOR VERTICAL AND HORIZONTAL PATTERNS

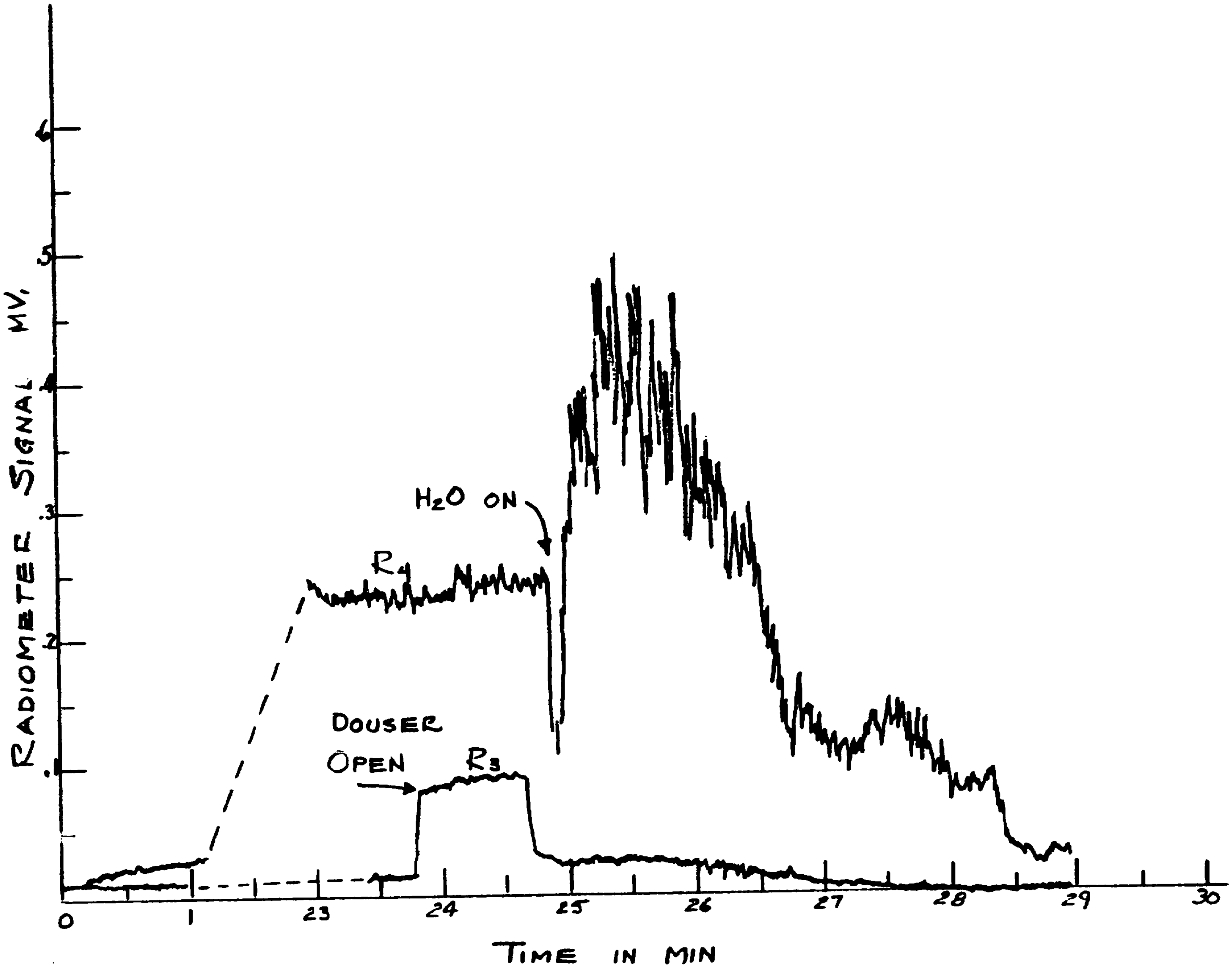


FIGURE 9 EFFECT OF WATER SPRAY ON THERMAL THREAT

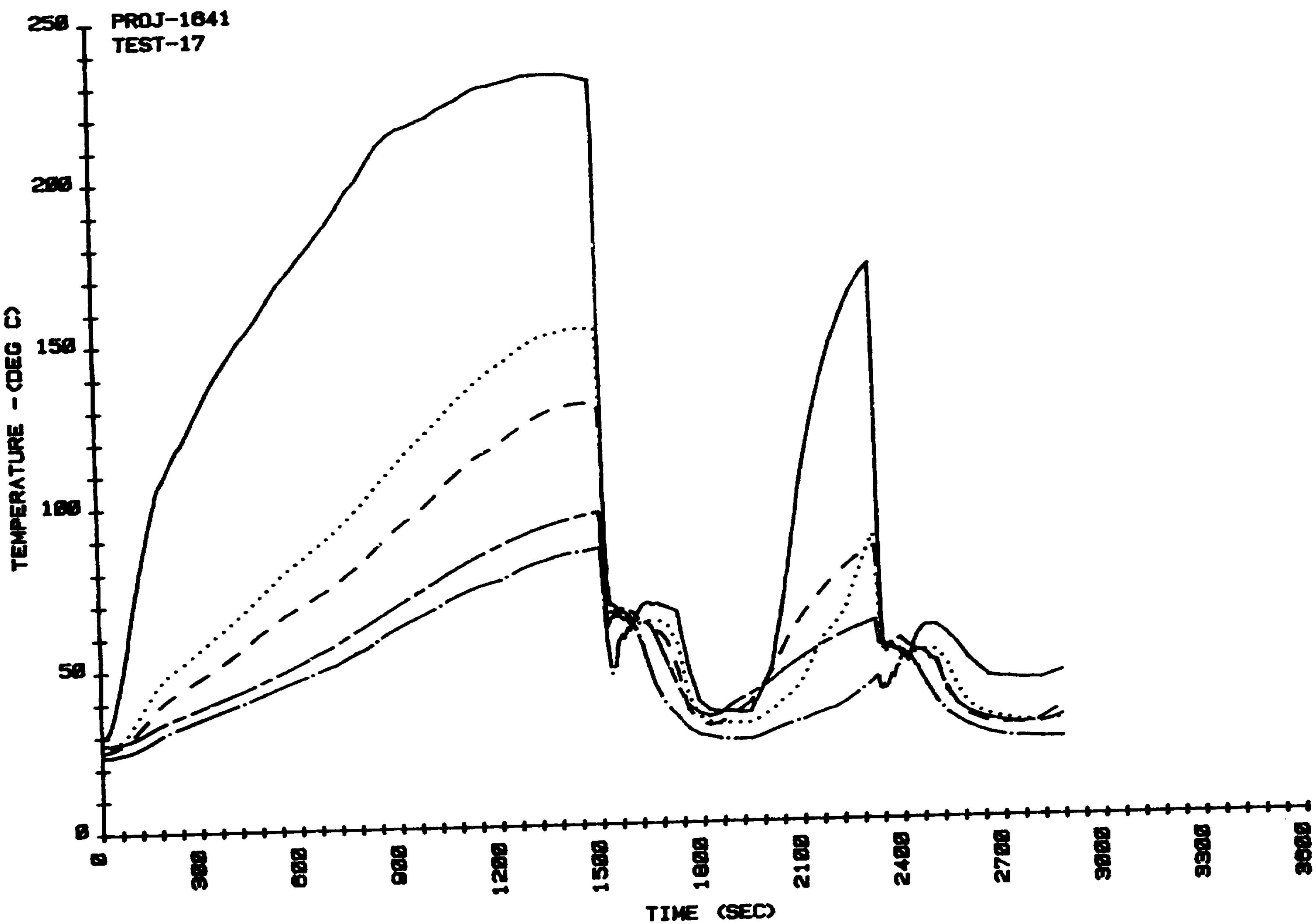


FIGURE 10 AIR TEMPERATURE CURVES FOR TEST 17